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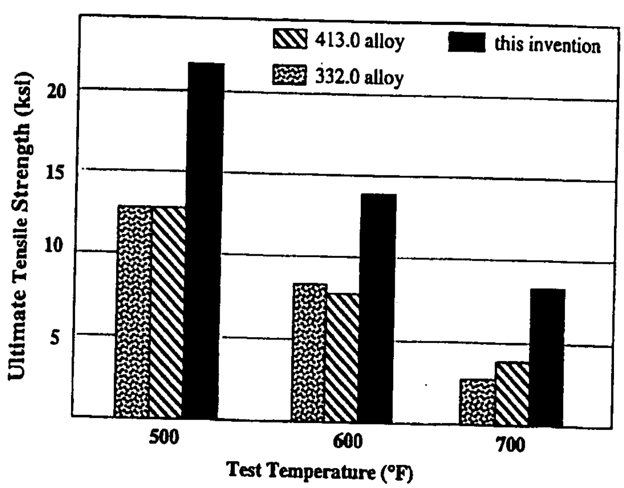
(54) Title: ALUMINUM-SILICON ALLOY HAVING IMPROVED PROPERTIES AT ELEVATED TEMPERATURES



(57) Abstract: Disclosed is an aluminum alloy suitable for high temperature applications, such as heavy duty pistons and other internal combustion applications, having the composition, by weight percent (wt %): Silicon 6.0 to 14.0, Copper 3.0 to 8.0, Iron 0.01 to 0.8, Magnesium 0.5 to 1.5, Nickel 0.05 to 1.2, Manganese 0.01 to 1.0, Titanium 0.05 to 1.2, Zirconium 0.05 to 1.2, Vanadium 0.05 to 1.2, Strontium 0.001 to 0.10, Aluminum balance. After the article is cast from this alloy the article is treated to a solutionizing step which dissolves unwanted precipitates and reduces any segregation present in the original alloy. After the solutionizing step, the article is quenched and is then aged at an elevated temperature for maximum strength. Iron and manganese may be present as impurities in the alloy in amounts less than 1.0 wt.%.

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ALUMINUM-SILICON ALLOY HAVING IMPROVED PROPERTIES AT ELEVATED TEMPERATURES

RELATED APPLICATIONS

This application is a continuation in part of Application Serial Number 09/152,469, filed September 8, 1998, for Aluminum Alloy having Improved Properties.

ORIGIN OF THE INVENTION

This invention described herein was made under a NASA contract and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the contractor has elected not to retain title.

BACKGROUND OF THE INVENTION

1. Field of the invention

This invention relates to aluminum alloys and specifically to high tensile strength aluminum-silicon hypoeutectic and eutectic alloys suitable for high temperature applications such as heavy duty pistons and other internal combustion applications.

2. Prior art

Aluminum-Silicon (Al-Si) casting alloys are the most versatile of all common foundry cast alloys in the production of pistons for automotive engines. Depending on the Si concentration in weight percent, the Al-Si alloy systems fall into three major categories: hypoeutectic (< 12 wt% Si), eutectic (12-13 wt% Si) and hypereutectic (14-25 wt % Si). However, commercial applications for hypereutectic alloys are relatively limited because they are among the most difficult Al alloys to cast and machine due to the high Si contents. When high Si content is alloyed into Al, it adds a large amount of heat capacity that must be removed from the alloy to solidify it during a casting operation. Significant variation in the sizes of the primary Si particles can be found between different regions of the cast article; resulting in a significant variation in the mechanical properties for the cast article. The primary crystals of Si must be refined in order to achieve hardness and good wear resistance property. For these reasons, hypereutectic alloys are not very economical to produce because they have a broad solidification range that results in poor castability and requires special foundry's process to control the high heat of fusion and microstructure. Furthermore, expensive diamond toolings must be used to machine parts such as pistons that are made from hypereutectic Al-Si castings. On the other hand, the usage of hypoeutectic and eutectic alloys are very popular for the industry because they are more economical to produce by casting, simpler

to control the cast parameters and easier to machine than hypereutectic. However, most of them are not suitable for high temperature applications, such as in the automotive field, for the reason that their mechanical properties, such as tensile strength, are not as high as desired in the temperature range of 500 °F-700 °F. Current state-of-the-art hypoeutectic and eutectic alloys are intended for applications at temperatures of no higher than about 450 °F. Above this elevated service temperature, the major alloy strengthening phases such as the θ' (Al_2Cu) and S' (Al_2CuMg) will precipitate rapidly, coarsen or dissolve and transform themselves into the more stable θ (Al_2Cu) and S (Al_2CuMg) phases. This undesirable microstructure and phase transformation results in drastically reduced mechanical properties, more particularly the ultimate tensile strengths and high cycle fatigue strengths for hypoeutectic and eutectic Al-Si alloys.

One approach taken by the prior art is to use ceramic fibers or ceramic particulates to increase the strength of hypoeutectic and eutectic Al-Si alloys. This approach is known as the aluminum Metal Matrix Composites (MMC) technology. For example, R. Bowles has used ceramic fibers to improve tensile strength of a hypoeutectic 332.0 alloy, in a paper entitled "Metal Matrix Composites Aid Piston Manufacture", Manufacturing Engineering, May 1987. Moreover, A. Shakesheff has used ceramic particulate for reinforcing another type of hypoeutectic A359 alloy, as described in "Elevated Temperature Performance of Particulate Reinforced Aluminum Alloys", Materials Science Forum, Vol. 217-222, pp. 1133-1138 (1996). In a similar approach, cast aluminum MMC for pistons using eutectic alloy such as 413.0 type, has been

described by P. Rohatgi in a paper entitled "Cast Aluminum Matrix Composites for Automotive Applications", Journal of Metals, April 1991.

Another approach taken by the prior art is the use of Ceramic Matrix Composites (CMC) technology in the place of hypoeutetic and eutectic alloys. For example, W. Kowbel has described the use of non-metallic carbon-carbon composites for making pistons to operate at high temperatures in a paper entitled "Applications of Net-Shape Molded Carbon-Carbon Composites in IC Engines", Journal of Advanced Materials, July 1996. Unfortunately, the material and processing costs of these MMC and CMC technology approaches are substantially higher than those produced using conventional casting and they cannot be considered for large usage in mass production, such as engine pistons.

SUMMARY OF THE INVENTION

The first aspect of this invention is to provide a composition of an aluminum alloy that can be used as a hypoeutectic or eutectic Al-Si alloy which is more economical to produce by conventional gravity casting and easier to machine than the hypereutectic alloys. In a second aspect of this invention, a composition has been devised to improve mechanical properties of such alloys that are suitable for high temperature applications such as heavy duty pistons and other internal combustion applications.

An aluminum alloy having the composition, by weight percent (wt %):

Silicon	6.0 to 14.0
Copper	3.0 to 8.0
Iron	0.05 to 0.8
Magnesium	0.5 to 1.5
Nickel	0.05 to 1.2
Manganese	0.05 to 1.0
Titanium	0.05 to 1.2
Zirconium	0.05 to 1.2
Vanadium	0.05 to 1.2
Strontium	0.001 to 0.10
Aluminum	balance

After the article is gravity cast from this alloy the article is treated to a solutionizing step which dissolves unwanted precipitates and reduces any segregation present in the original alloy. After the solutionizing step, the article is quenched and is then aged at an elevated temperature for maximum strength. Iron and manganese may be present as impurites in the alloy in amounts less than 1.0 wt%.

DESCRIPTION OF THE DRAWING

Figure 1 is a chart showing a comparison of this new alloy with typical conventional hypoeutectic (332.0) and eutectic (413.0) alloys, the chart showing tensile

strength, tested at 500 °F, 600 °F and 700 °F after exposure of the cast article to a temperature of 500 °F for 100 hours, 600 °F for 100 hours and 700 °F for 100 hours.

DETAILED DESCRIPTION OF THE INVENTION

The alloy of the invention is marked by an ability to perform in cast form at high servicing temperature. However, best properties are obtained in the forged and heated conditions. The aluminum alloy of this invention, suitable for high temperature applications and can be used as a hypoeutectic or eutectic Al-Si alloy, is composed of the following elements, by weight percent:

Silicon	6.0 to 14.0
Copper	3.0 to 8.0
Iron	0.05 to 0.8
Magnesium	0.5 to 1.5
Nickel	0.05 to 1.2
Manganese	0.05 to 1.0
Titanium	0.05 to 1.2
Zirconium	0.05 to 1.2
Vanadium	0.05 to 1.2
Strontium	0.001 to 0.10
Aluminum	balance

The alloy may contain as impurities less than 0.2 weight percent of zinc and chrominum. Iron and manganese may be omitted from the alloy. However, these elements tend to exist as impurities in most aluminum alloys due to common foundry practices. Eliminating them completely from the alloy (i.e., by alloy refining techniques) will increase the cost of the alloy significantly.

Silicon gives the alloy a high elastic modulus and low thermal expansion when the concentration is greater than 10 % wt. Si. For this reason, a low thermal expansion property is an important factor for eutectic alloy (12% - 13%). Finally, the addition of Si also improves fluidity of molten aluminum alloy to enhance the castability. The alloy will not require expensive diamond toolings for machining if the silicon concentration is kept well below about 14 wt %.

Copper coexists with magnesium and forms a solid solution in the matrix to give the alloy age-hardening properties, thereby improving the high temperature strength. Copper also form the θ' intermediate phase (Al_2Cu) and is the most potent strengthening element in this new alloy. The enhanced high strength at high temperatures will be affected if the copper wt% level is not adhered to.

Titanium and vanadium form primary crystals of Al-Ti and Al-V compounds. Since these crystallized intermetallic compounds act as nuclei for solidification, the grain

size upon solidification is fine. Titanium and vanadium also function as dispersion strengthening mechanism, in order to improve the high temperature tensile strength.

Zirconium forms primary crystals of an Al-Zr compound. The crystallized intermetallic compounds also act as particles for dispersion strengthening. Zirconium also forms a solid solution in the matrix to a small amount, thus enhancing the formation of GP (Guinier-Preston) zones which are the Cu-Mg rich regions, and the θ' intermediate phase in the Al-Cu-Mg system to improve the age-hardening properties.

Iron gives strength and also prevents adhesion to the steel die in which the article is cast. In general, iron is difficult to control because the aluminum alloy will tend to pick up iron from scrap materials and the steel ladle and mold in the casting foundry. Nickel improves tensile strength at elevated temperatures by forming Al-Cu-Ni intermetallic compounds.

Strontium is used to modify the Al-Si eutectic phase. The strength and ductility of hypoeutectic and eutectic can be substantially improved by using Strontium as a Al-Si modifier. Effective modification can be achieved at very low additional level, but a range of recovered strontium of 0.01 to 0.05 wt.% is commonly used.

The alloy of this invention is marked by an ability to perform in cast form using conventional gravity cast or die casting. This alloy can be cast conventionally in the temperature range of about 1325 °F to 1450 °F. However, best properties are obtained in

the forged, special casting technique such as squeeze casting and heat treated conditions. Castings of this alloy are cast into approximate shape and are then machined or ground to final dimensions.

An article, such as an engine block or a piston, is cast from the alloy and the article is then solutionized at a temperature of 900 °F to 1000 °F for fifteen minutes to four hours. The purpose of the solutionizing is to dissolve unwanted precipitates and reduce any segregation present in the alloy. For uses at temperatures of 500 °F to 700 °F the solutioning treatment is not required..

After solutionizing, the article is quenched in a quenching medium at a temperature within the range of 120 °F to 300 °F. The most preferred quenching medium is boiling water. After quenching, the article is aged at a temperature of 410 °F to 490 °F for four to 16 hours. Preferably, the aging process is preformed at a temperature within the range of 425 °F to 485 °F for six to 12 hours.

The following table illustrates the superior qualities of this new alloy. This table compare the tensile strengths of this invention, with two well known hypoeutectic (332.0) and eutectic (413.0) alloys, after an article cast from this alloy has been held at 500, 600 and 700 F for 100 hours. The articles were tested at 500 °F, 600 °F and 700 °F, respectively. It will be noted that the tensile strength of this new alloy is almost twice that of the known hypoeutectic and eutectic alloys.

Ultimate Tensile Strength (ksi) at Test Temperatures (°F)

Alloy	500 °F	600 °F	700 °F
This invention	22	14	7
332.0 (hypoeutectic)	13	7.5	3.5
413.0 (eutectic)	13	7	4.5

What is claimed is:

1. An aluminum alloy suitable for high temperature applications is composed of the following elements, by weight percent :

Silicon	6.0 to 14.0
Copper	3.0 to 8.0
Iron	0.01 to 0.8
Magnesium	0.5 to 1.5
Nickel	0.05 to 1.2
Manganese	0.01 to 1.0
Titanium	0.05 to 1.2
Zirconium	0.05 to 1.2
Vanadium	0.05 to 1.2
Strontium	0.001 to 0.10
Aluminum	balance

2. The alloy of Claim 1 wherein the alloy contains as impurities less than 1.0 weight percent of iron and manganese.

3. An article cast from the alloy of Claim 1.

4. The alloy of Claim 3 wherein the alloy contains as impurities less than 0.2 weight percent zinc and chromium.

5. An article cast from the alloy of Claim 2.

6. The article of Claim 4 having a tensile strength of at least 20 ksi at 500 °F after being aged at a temperature within the range of 400 °F to 500 °F for four to 16 hours.

7. An article cast from the alloy of Claim 4.

8. A process for making a cast article having improved tensile strength at elevated temperature, comprising:

a. Casting the article from an alloy having a composition by weight percent

Silicon	6.0 to 14.0
Copper	3.0 to 8.0
Iron	0.01 to 0.8
Magnesium	0.5 to 1.5
Nickel	0.05 to 1.2
Manganese	0.01 to 1.0
Titanium	0.05 to 1.2

Zirconium	0.05 to 1.2
Vanadium	0.05 to 1.2
Strontium	0.001 to 0.10
Aluminum	balance

b. Aging the article at a temperature within the range of 400 °F to 500 °F for a time period within the range of four to 16 hours.

9. The process of Claim 8 wherein the article is exposed to a solutionizing step prior to said aging, said solutionizing step being carried out by exposing the cast article to a temperature within the range of 900 °F to 1000 °F for a time period of fifteen minutes to four hours.

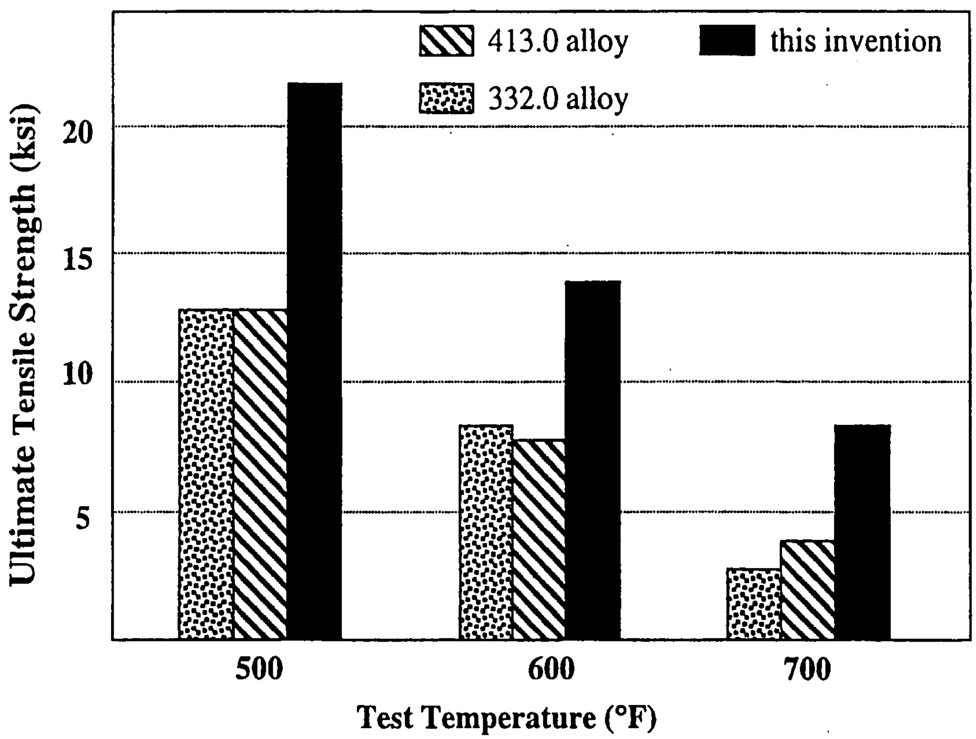
10. The process of Claim 8 wherein the cast article is aged at a temperature within the range of 425 °F to 485 °F for 4 to 12 hours.

11. The process of Claim 8 wherein the alloy contains as impurities less than 1.0 weight percent of iron and manganese.

12. The process of Claim 8 wherein the solutionizing step is followed by a quenching step, the article being quenched in a quenching medium at a temperature within the range of 120 °F to 300 °F.

13. The process of Claim 12 wherein the temperature of the quenching medium is within the range of 170 °F to 250 °F.

14. The process of Claim 14 wherein the quenching medium is boiling water.


413.0 alloy
this invention
332.0 alloy
Ultimate Tensile Strength (ksi)
20
15
10
5
500
600
700
Test Temperature (°F)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/20314

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :C22F 1/04; C22C 21/16
US CL : 148/549, 550, 551, 552, 700, 439; 420/535

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 148/549, 550, 551, 552, 700, 439; 420/535

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CAS ONLINE
search terms: aluminum, Al, copper, Cu, silicon, Si, solution, quenching, aging, boiling.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,789,607 A (FUJITA et al.) 06 December, 1988, abstract.	1-7
X	DE 4404420 A1 (HOFMANN et al.) 17 August 1995, abstract.	1-7
Y	GB 2300198 A1 (JARRETT) 30 October 1996, abstract.	1-14
Y	JP 50009513 A2 (IWATA et al.) 31 January 1975, abstract.	8-14
Y	JP 08104937 A2 (KITAOKA et al.) 23 April 1996, abstract.	8-14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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